

## EJECTOR CYCLE

## CROSS-REFERENCE TO RELATED APPLICATION

This application is related to and claims priority from  
5 Japanese Patent Application No. 2002-202724 filed on July 11,  
2002, the contents of which are hereby incorporated by reference.

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention:

10 The present invention relates to an ejector cycle including  
an ejector. In the ejector cycle, a variable throttle is disposed  
upstream from a nozzle of the ejector, so that high-pressure  
refrigerant is decompressed in the variable throttle, before  
being decompressed in the nozzle.

## 15 2. Description of Related Art:

In an ejector cycle, refrigerant is decompressed and  
expanded in a nozzle of an ejector so that gas refrigerant  
evaporated in an evaporator is sucked, and pressure of  
refrigerant to be sucked into a compressor is increased by  
20 converting expansion energy to pressure energy. In the nozzle  
of the ejector, the pressure energy of the refrigerant is  
converted to the speed energy thereof. Further, because  
refrigerant passing through the nozzle is decompressed to stride  
over the saturation liquid line, refrigerant boils near an inner  
25 wall surface defining a throttle portion of the nozzle. On the  
other hand, in a center portion separated from the inner wall  
surface, because refrigerant is difficult to boil, liquid dorps

of refrigerant are difficult to become minute. Therefore, nozzle efficiency and ejector efficiency may be decreased in the ejector cycle.

To overcome this problem, in JP-A-5-149652, a fixed throttle is disposed upstream from a nozzle in an ejector, so that refrigerant is decompressed by the fixed throttle and the nozzle in two steps. That is, refrigerant boils once in the fixed throttle at the first step, and the refrigerant is expanded at an inlet of the nozzle so as to boils in the nozzle at the second step while generating a bubble core. In the ejector, because the first throttle is the fixed throttle, a flow amount cannot be adjusted. Therefore, the nozzle efficiency and the ejector efficiency of the ejector cycle cannot be improved in a wide load variation area.

#### SUMMARY OF THE INVENTION

In view of the foregoing problems, it is an object of the present invention to provide an ejector cycle having an ejector, which effectively improves an ejector efficiency and a nozzle efficiency in a wide load variation area of the ejector cycle.

According to an ejector cycle of the present invention, an ejector includes a nozzle for decompressing and expanding refrigerant flowing from a high-pressure heat exchanger by converting pressure energy of refrigerant to speed energy of the refrigerant, and a pressure-increasing portion that is disposed to increase a pressure of refrigerant by converting the speed energy of refrigerant to the pressure energy of refrigerant while

mixing refrigerant injected from the nozzle and refrigerant sucked from a low-pressure heat exchanger. Further, a gas-liquid separator for separating refrigerant from the ejector into gas refrigerant and liquid refrigerant, includes a gas refrigerant outlet coupled to a refrigerant suction side of a compressor, and a liquid refrigerant outlet coupled to a refrigerant inlet side of the low-pressure heat exchanger. In the ejector cycle, a variable throttle is disposed in a refrigerant passage between a high-pressure heat exchanger and the ejector, and the variable throttle has a throttle opening degree that is variable such that a refrigerant super-heating degree at a refrigerant outlet side of the low-pressure heat exchanger or at a refrigerant suction side of the compressor becomes in a predetermined range. Therefore, it is possible to suitably decompress refrigerant before being introduced into the nozzle of the ejector. Accordingly, ejector efficiency and nozzle efficiency can be effectively improved while a sufficient cooling capacity can be obtained in the ejector cycle, in a wide load vibration area of the ejector cycle.

Preferably, the variable throttle is disposed to decompress high-pressure refrigerant from the high-pressure heat exchanger, to a gas-liquid two-phase state. Therefore, the nozzle efficiency and the ejector efficiency can be effectively improved in the wide load vibration area of the ejector cycle.

For example, the variable throttle is a mechanical expansion valve that mechanically operates based on the refrigerant super-heating degree sensed by a sensing portion.

Alternatively, the variable throttle is an electrical throttle that is electrically operated based on the refrigerant super-heating degree detected by a sensor. Accordingly, the throttle opening degree of the variable throttle can be accurately controlled based on the super-heating degree.

Preferably, at least a part of the variable throttle is integrated with the ejector. In this case, the structure of the ejector cycle can be made simple, and the size of the ejector cycle can be reduced.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and advantages of the present invention will be more readily apparent from the following detailed description of preferred embodiments when taken together with the accompanying drawings, in which:

FIG. 1 is a schematic diagram showing an ejector cycle according to a first preferred embodiment of the present invention;

FIG. 2A is a Mollier diagram (p-h diagram) showing decompression operation of a variable throttle and a nozzle of an ejector in the ejector cycle, and FIG. 2B is an enlarged schematic diagram for explaining the decompression operation in the ejector cycle, according to the first embodiment;

FIG. 3 is a schematic diagram showing an ejector cycle according to a second preferred embodiment of the present invention;

FIG. 4 is a schematic diagram showing an example of an ejector cycle according to a third preferred embodiment of the present

invention; and

FIG. 5 is a schematic diagram showing another example of the ejector cycle according to the third embodiment.

5            DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described hereinafter with reference to the appended drawings.  
(First Embodiment)

10           In the first embodiment, an ejector cycle is typically used  
for a vapor compression refrigerator used for a showcase for  
refrigerating foods. As shown in FIG. 1, a compressor 10 is an  
electric compressor for sucking and compressing refrigerant  
circulated in the ejector cycle. A radiator 20 is a high-pressure  
heat exchanger for cooling high-temperature and high-pressure  
15           refrigerant discharged from the compressor 10 by performing  
heat-exchange operation between outside air and the high-  
temperature and high-pressure refrigerant. Further, an  
evaporator 30 is a low-pressure heat exchanger for cooling air  
to be blown into the showcase by evaporating liquid refrigerant,  
20           more specifically, by performing heat-exchange operation between  
the air and low-pressure refrigerant. An ejector 40 sucks  
refrigerant evaporated in the evaporator 30 while decompressing  
and expanding refrigerant flowing out from the radiator 20 in  
a nozzle 41, and increases pressure of refrigerant to be sucked  
25           into the compressor 10 by converting expansion energy to pressure  
energy.

The ejector 40 includes the nozzle 41, a mixing portion 42,

a diffuser 43 and the like. The nozzle 41 decompresses and expands high-pressure refrigerant flowing into the ejector 40 in iso-enthalpy by converting pressure energy of the high-pressure refrigerant from the radiator 20 to speed energy thereof.

5 The mixing portion 42 sucks refrigerant evaporated in the evaporator 30 by using an entrainment function of high-speed refrigerant stream injected from the nozzle 41, and mixes the sucked refrigerant and the injected refrigerant. Further, the diffuser 43 mixes the refrigerant injected from the nozzle 41  
10 and the refrigerant sucked from the evaporator 30, and increases the refrigerant pressure by converting speed energy of the mixed refrigerant to pressure energy thereof.

In the mixing portion 42, a drive stream of refrigerant from the nozzle 41 and a suction stream of the refrigerant from the  
15 evaporator 30 are mixed so that their momentum sum is conserved, thereby increasing refrigerant pressure. In the diffuser 43, because a refrigerant passage sectional area gradually increases toward its outlet, the refrigerant speed energy (dynamic pressure) is converted to refrigerant pressure energy (static  
20 pressure). Thus, in the ejector 40, refrigerant pressure is increased by both of the mixing portion 42 and the diffuser 43. Accordingly, in the ejector 40, a pressure-increasing portion is constructed with the mixing portion 42 and the diffuser 43.

In the first embodiment, "Laval nozzle" (refer to Fluid  
25 Engineering published by Tokyo University Publication) is adopted as the nozzle 41 to accelerate refrigerant injected from the nozzle 41 equal to or higher than the sound velocity. Here,

the Laval nozzle 41 includes a throttle 41a having the smallest passage area in its refrigerant passage. However, a nozzle tapered toward its outlet can be used as the nozzle 41.

In FIG. 1, refrigerant is discharged from the ejector 40, and flows into a gas-liquid separator 50. The gas-liquid separator 50 separates the refrigerant from the ejector 40 into gas refrigerant and liquid refrigerant, and stores the separated gas refrigerant and the separated liquid refrigerant therein. The gas-liquid separator 50 includes a gas-refrigerant outlet connected to a suction port of the compressor 10, and a liquid-refrigerant outlet connected to an inlet of the evaporator 30. Accordingly, in the ejector cycle, liquid refrigerant flows into the evaporator 30 while refrigerant from the radiator 20 is decompressed in the nozzle 41 of the ejector 40.

A throttle 60 is disposed for decompressing refrigerant flowing from the gas-liquid separator 50 toward the evaporator 30. An oil return passage 70 is provided in the gas-liquid separator 50, so that lubrication oil separated by the gas-liquid separator 50 is sucked to the compressor 10.

A variable throttle 80 is disposed in a refrigerant passage between the radiator 20 and the ejector 40. The variable throttle 80 is an expansion valve disposed upstream from the nozzle 41 of the ejector, which decompresses high-pressure refrigerant flowing from the radiator 20 to a gas-liquid two-phase state. The variable throttle 80 controls a throttle opening degree so that a super-heating degree of refrigerant at an outlet side of the evaporator 30 becomes in a predetermined range (e.g., 0.1

- 10 degrees). The variable throttle 80 can have a structure similar to a well-known thermal expansion valve.

Specifically, the variable throttle 80 includes a temperature sensing portion 81 that senses a refrigerant temperature at the refrigerant outlet side of the evaporator 30, and controls the throttle opening degree by a balance between a gas pressure within the temperature sensing portion 81, a pressure in the evaporator 30 and a spring pressure of the variable throttle 80. Accordingly, when the pressure in the evaporator 30, that is, a thermal load in the evaporator becomes larger, the throttle opening degree of the variable throttle 80 becomes larger. Conversely, when the pressure in the evaporator 30, that is, the thermal load in the evaporator 30 becomes lower, the throttle opening degree of the variable throttle 80 becomes smaller.

In the first embodiment, a valve body 82 of the variable throttle 80 is integrated with the ejector 40, so that the size of a decompression portion constructed with the variable throttle 80 and the ejector 40 is reduced.

Next, operational effects of the ejector 40 according to the first embodiment will be now described. As shown in FIG. 1, refrigerant discharged from the compressor 10 circulates toward the radiator 20. Then, high-pressure refrigerant is cooled in the radiator 20 and is decompressed in the variable throttle 80 in iso-enthalpy to a gas-liquid two-phase state. Thereafter, refrigerant from the variable throttle 80 is further decompressed in the nozzle 41 of the ejector 40 in iso-enthalpy,



so that the refrigerant speed at the outlet of the nozzle 41 of the ejector becomes equal to or higher than the speed of the sound. Thereafter, refrigerant from the outlet of the nozzle 41 flows into the mixing portion 42 of the ejector 40.

5           FIGS. 2A and 2B show a refrigerant state by the decompression operation at two steps in the ejector cycle. In FIG. 2B, the valve body 82 of the variable valve 80 and the nozzle 41 of the ejector 40 are simply integrally indicated for explaining the two-step decompression due to the variable valve 80 and the nozzle  
10   41. As shown in FIGS. 2A and 2B, refrigerant flows into the variable throttle 80 as shown by (1) in FIG. 2B, and is decompressed by the variable throttle 80 as shown by (2) in FIG. 2B so as to boils once at an inlet side of the nozzle 41. That is, as shown by (3) in FIG. 2B, bubbles are generated by the  
15   variable valve 80, and boiling cores are generated after the bubbles disappear at the inlet side of the nozzle 41. Refrigerant with the boiling cores is further boiled by the nozzle 41, so that fine liquid drops (i.e., minute liquid drops) of refrigerant are generated as shown by (4) in FIG. 2B. Because the boiling  
20   of refrigerant is facilitated in the nozzle 41, the generation of minute liquid drops of the refrigerant can be facilitated in the nozzle 41. Accordingly, the nozzle efficiency can be effectively improved.

          In the first embodiment, freon is used as the refrigerant  
25   so that a refrigerant pressure at the high pressure side is lower than the critical pressure of the refrigerant. Therefore, the refrigerant pressure flowing into the nozzle 41 is lower than

the critical pressure of the refrigerant.

The mixing portion 42 sucks refrigerant evaporated in the evaporator 30 by using the entrainment function of high-speed refrigerant stream injected from the nozzle 41, and mixes the sucked refrigerant and the injected refrigerant. Further, the diffuser 43 mixes the refrigerant injected from the nozzle 41 and the refrigerant sucked from the evaporator 30, and increases the refrigerant pressure. Therefore, the ejector efficiency can be improved. Accordingly, low-pressure refrigerant in the gas liquid separator 50 circulates the throttle 60, the evaporator 30 and the pressure increasing portion of the ejector 40, in this order, and returns to the gas-liquid separator 50.

According to the first embodiment of the present invention, the refrigerant is decompressed by the variable valve 80 to the gas-liquid two-phase refrigerant at an upstream side of the throat portion 41a of the nozzle 41. Therefore, it can prevent the refrigerant from being throttled more than a necessary degree while the ejector efficiency can be effectively improved. Further, because the throttle opening degree of the variable valve is controlled based on the thermal load (e.g., the super-heating degree of the refrigerant at the outlet side of the evaporator 30), the ejector efficiency of the ejector cycle can be improved even when the cooling load (air conditioning load) is changed. Thus, the ejector cycle can be used in a wide load variation area, while the ejector efficiency, the nozzle efficiency and the cooling capacity of the ejector cycle are improved.

(Second Embodiment)

In the above-described first embodiment, the throttle opening degree of the variable throttle 80 is controlled so that the super-heating degree of the refrigerant at the outlet side of the evaporator 30 becomes in the predetermined range. However, in the second embodiment, the throttle opening degree of the variable throttle 80 is controlled so that the super-heating degree of the refrigerant at a refrigerant suction side of the compressor 10 becomes in a predetermined range (e.g., 0.1 - 30 degrees). That is, the temperature sensing portion 81 is disposed at the refrigerant suction side of the compressor 10, and the throttle opening degree of the variable throttle 81 is controlled so that the super-heating degree at the refrigerant suction side of the compressor 10 becomes in the predetermined range.

In the second embodiment, the other parts are similar to those of the above-described first embodiment, and detail description thereof is omitted. Therefore, the advantages described in the above-first embodiment can be obtained.

(Third Embodiment)

In the above-described first and second embodiments, the variable throttle 80 is a mechanical variable throttle in which its throttle opening degree is mechanically changed based on the pressure difference and the like. However, in the third embodiment, as shown in FIGS. 4 and 5, an electrical temperature sensor 84 is disposed to detect a refrigerant temperature, and an actuator 83 is controlled by an electronic control unit (ECU) based on the signal from the electrical temperature sensor 84,

so that the throttle opening degree of the variable throttle 80 is controlled. In the example of FIG. 4, the electrical temperature sensor 84 is disposed at the refrigerant outlet side of the evaporator 30 to detect the refrigerant temperature (refrigerant super-heating degree) at the refrigerant outlet side of the evaporator 30. Therefore, in this case, the ECU controls the actuator 63 to control the throttle opening degree of the variable throttle 80, so that the super-heating degree at the refrigerant outlet side of the evaporator 30 becomes in a predetermined range. On the other hand, in the example of FIG. 5, the electrical temperature sensor 84 is disposed at the refrigerant suction side of the compressor 10 to detect the refrigerant temperature (refrigerant super-heating degree) at the refrigerant suction side of the compressor 10. Therefore, in this case, the ECU controls the actuator 83 to control the throttle opening degree of the variable throttle 80, so that the super-heating degree at the refrigerant suction side of the compressor 10 becomes in a predetermined range.

In the third embodiment, the other parts are similar to those of the above-described first embodiment, and detail description thereof is omitted. Therefore, the advantages described in the above-first embodiment can be obtained.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art.

For example, in the above-described embodiments of the present invention, freon is used as the refrigerant in the ejector cycle. However, the present invention can be applied to an ejector cycle where carbon dioxide is used as the refrigerant. Even in this case, refrigerant is decompressed by two steps due to the variable throttle 80 and the nozzle 41, and the throttle opening degree of the variable throttle 80 can be controlled based on the thermal load at the low-pressure side in the ejector cycle. Further, the present invention can be applied to an ejector cycle where the refrigerant pressure at the high-pressure side is equal to or higher than the critical pressure of the refrigerant.

In the above-described embodiments of the present invention, the ejector cycle is used for the vapor-compression refrigerator for cooling the showcase for refrigerating foods. However, the ejector cycle of the present invention can be used for an air conditioner. Further, in the above-described embodiments, the super-heating degree of the low-pressure refrigerant at the refrigerant outlet side of the evaporator 30 or at the refrigerant suction side of the compressor 10 in the ejector cycle is mechanically or electrically detected from the refrigerant temperature. Generally, the refrigerant temperature is related to the refrigerant pressure. Therefore, the super-heating degree of the low-pressure refrigerant in the ejector cycle can be mechanically or electrically detected from the refrigerant pressure.

Further, in the above-described embodiments, refrigerant is decompressed to the gas-liquid two-phase state by the variable

throttle 80, before refrigerant flowing into the throttle portion 41a of the nozzle 41 of the ejector 40. However, the variable throttle 80 is not limited to decompress refrigerant to the gas-liquid two-phase state. That is, the variable throttle 80 can decompress the high-pressure refrigerant from the radiator 20 to a suitable decompression state, before refrigerant flowing into the throttle portion 41a of the nozzle 41. In addition, in the above-described embodiments, the variable throttle 80 can be decompressed in iso-entropy.

Such changes and modifications are to be understood as being within the scope of the present invention as defined by the appended claims.